A NEW CONCEPT OF SYNTHETIC APERTURE INSTRUMENT FOR HIGH RESOLUTION EARTH OBSERVATION FROM HIGH ORBITS

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RÉSUMÉ :
L'observation haute résolution de la Terre depuis l'orbite géostationnaire nécessite l'emploi de télescopes de grand diamètre irréalisables s'ils sont monolithiques. Pour contourner ce problème, il est nécessaire de « segmenter » l'instrument pour le rendre réalisable et pour pouvoir le placer sur orbite.
La Synthèse d'Ouverture Optique (SOO), utilisée en astronomie, peut être envisagée comme solution pour l'imagerie haute résolution depuis une orbite haute. Dans cet article, nous décrivons un concept instrumental de système imageur SOO à résolution et champ variables utilisant tout ou partie de ces composantes en adoptant une redécomposition des concepts d'interféromètres de type *Fizeau* ou *Michelson.* Concept qui autorise, en outre, de rendre le système plus robuste en cas de panne d'un des sous-systèmes. Cet instrument est actuellement à l'étude dans le département recherche d'Alcatel Space [1].

ABSTRACT :
High Resolution Earth Observation from high orbits (e.g. Geostationnary) requires the use of large diameter telescopes, unfeasible if considering monolithic concepts. It is necessary, to circumvent this problem, to consider a segmented instrument, turning it into a feasible concept that can be put into orbit.
Optical Aperture Synthesis (OAS) can be considered as a solution for HR observation from high orbits. In this paper, we describe a new OAS imaging instrument concept (under study in the Alcatel Space Research Department [1]) having variable resolution and field of view by adopting a re-decomposition of the basic *Michelson* or *Fizeau* interferometer schemes. In addition to providing variable resolution power and field of view, this instrument concept is particularly robust to sub-systems failure since it shows a natural redundancy of its imaging capabilities.

1 - INTRODUCTION

High resolution Earth Observation from Geostationnary orbit is of great interest since it permits accessibility, important for survey or alert type missions, and permanence, also important for real time missions. However it has a great impact on the optical instrument dimensions since the accessible resolution is proportional to the telescope diameter and inversely proportional to the satellite altitude. This is illustrated on the following graph:

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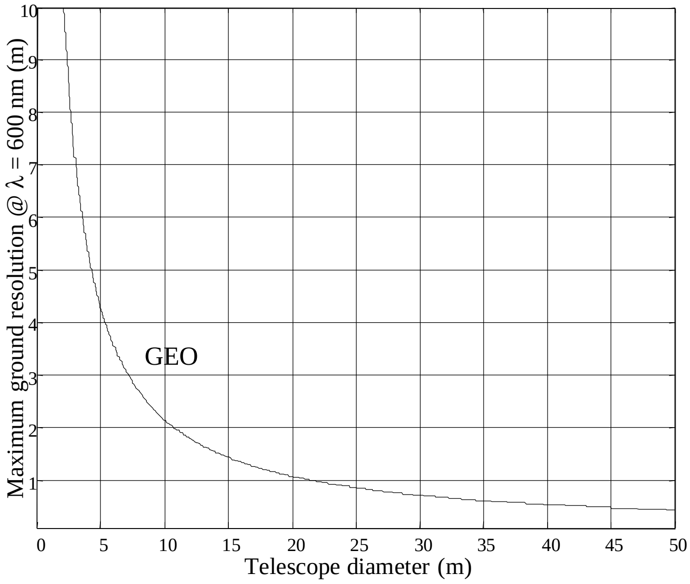


Figure 1 – variation of a geostationnary telescope diameter wrt ground resolution

When aiming to achieve a 1 m resolution type mission from the GEO orbit, the use of classical technology rapidly shows its limits and new non conventional solutions emerge such as :

- large flexible mirror that implies a complex structure due to the large envisaged diameter (ϕ > 15 m)
- deployable segmented mirror, which diameter is limited to ϕ ~ 5 m due to the room available under the launcher shroud. Such a diameter is not compatible with a metric resolution mission from the geostationnary orbit.
- Optical Aperture Synthesis using a multi-pupil system. This option is already used on ground for astronomy for several years [8]. It is a good candidate for an earth observation concept [6] and we believe that its extension to extended sources imagery could be envisaged at a 15/20 years horizon.

2 - OPTICAL APERTURE SYNTHESIS

2.1 - GENERAL OPTICAL APERTURE SYNTHESYS PRINCIPLE

An Optical Aperture Synthesis system is composed of separated elements (mirrors or telescopes) that collect the light coming from the observed scene. The largest distance that separates these collectors determines the angular resolution of the instrument. The synthetic pupil composed by all the collectors is called the entrance pupil of the system.

A supplementary device is necessary to combine coherently the light coming from each collector. This optical system imposes the width of the point spread function.

Two types of interferometers can be used for an optical aperture synthesis system. They are illustrated in Figure 2.

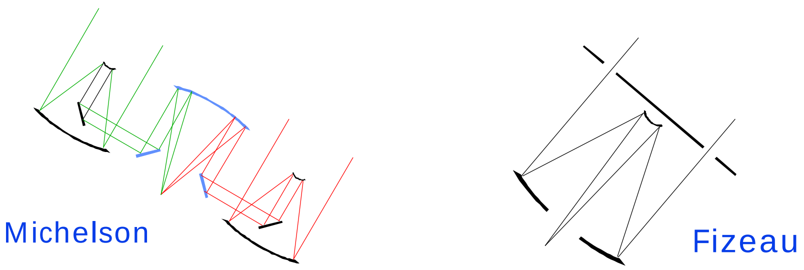


Figure 2 – Schematic representation of the two main interferometer types

Both concepts shows advantages and drawbacks :

- the Fizeau interferometer maintains the classical object-image relation since it is equivalent to a classical telescope but, as a consequence, its volume (distance M1-M2) is proportional to the expected resolution.
- In a Michelson type interferometer, the collecting and combining functions are separated. This has the advantage to reduce the overall dimensions of the whole instrument but it also generally reduces the field of view with respect to the one achievable with a Fizeau type interferometer [3][4][9].

3 - MULTI-INSTRUMENT CONCEPT

3.1 - CONCEPT DESCRIPTION

The global instrument, described here, is based on the interferometric combination of sub-instruments (see Figure 3), each of them being interferometers. These sub-instruments, having imaging capabilities, are composed of a minimum of three collectors.

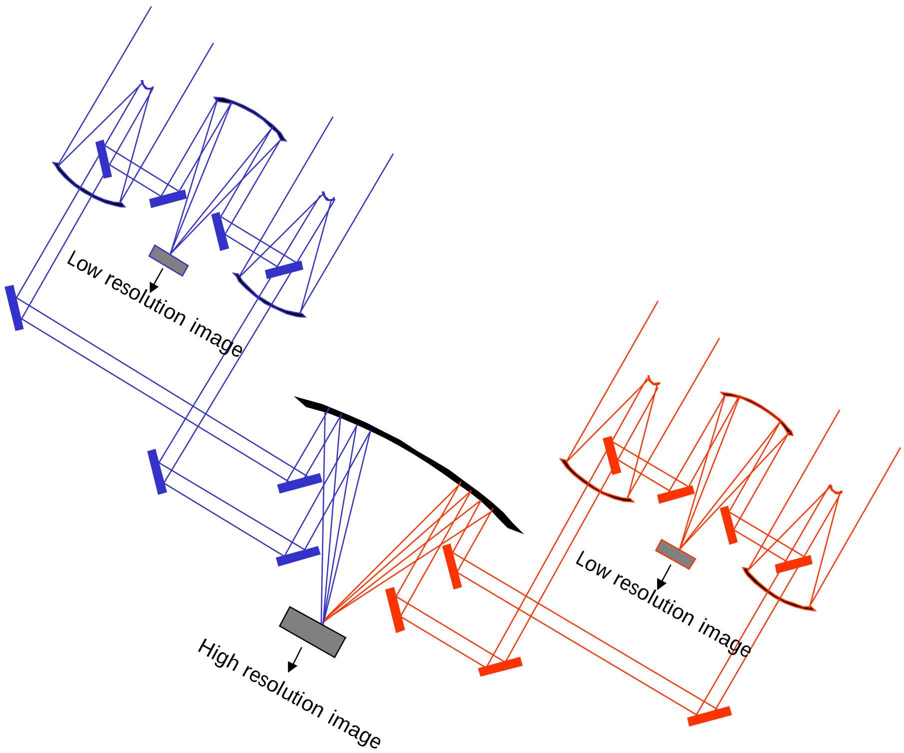


Figure 3 – Example (section view) of a multi-instrument Michelson concept.

The interferometric combination of all sub-instruments allows, by adapting observing times and deconvolution processing, to provide images which resolution is comparable to the one we would obtain with a telescope which diameter would be equivalent to the circle that contain the synthetic pupil. This operating mode is called High Resolution (HR).

A second mode called Low Resolution Large Field (LRLF) is associated to the HR one. This mode is obtained with each of the sub-instruments with an autonomous imaging capability authorising to carry on an observing mission (at a lower resolution) if one of the instruments or one of the satellites is subject to a failure.
Furthermore, sub-instruments can be pointed towards different regions. This operating mode is a way to perform a simultaneous observation of several fields of view in LRLF. HR mode can then be used to zoom on a particular zone.

In the LRLF mode, if all shot regions are contiguous then, by using a mosaicing method, the resulting image product is characterised by an extended field of view with a negligible parallax effect ([2]).

The following figure is an illustration of the different observing modes achievable with the multi-instrument.

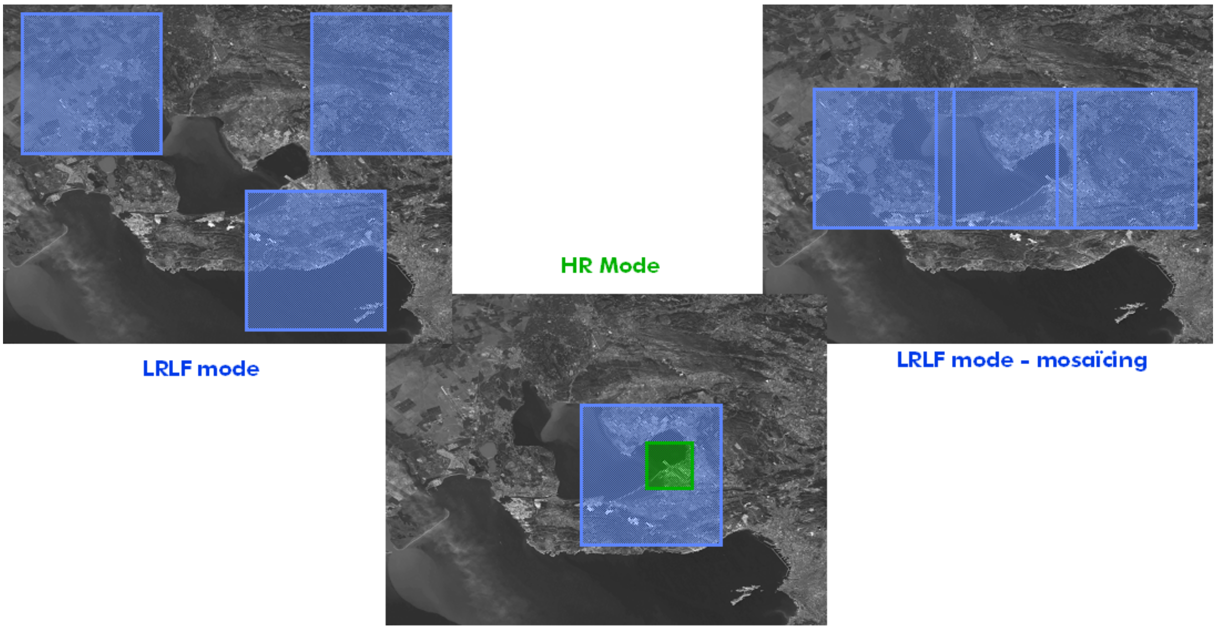


Figure 4 – Illustration of the imaging modes accessible to the multi-instrument

4 - EXAMPLE OF A 9-PUPIL MULTI-INSTRUMENT CONCEPT

As an example of the multi-instrument concept, we present a synthetic aperture imaging system made up of three sub-instruments; each sub-instrument consists of three telescopes operating in the interferometric mode.

The figure below is an artist view of the 3x3 pupil multi-instrument in the Michelson mode. The sub-instruments are supported by free flyer platforms.

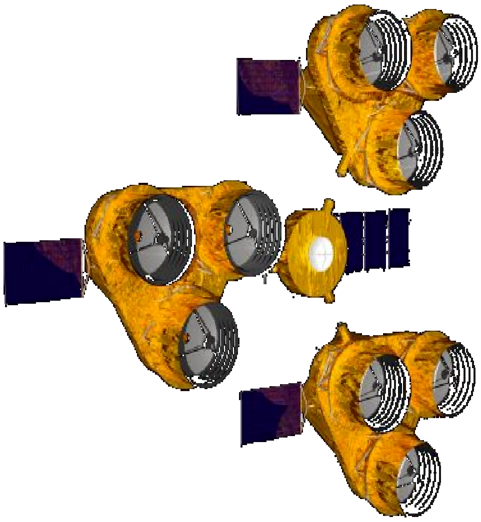


Figure 5 – Artist view of the 9 pupil multi-instrument in the Michelson mode.

4.1 - MULTI-INSTRUMENT OPTIMISATION

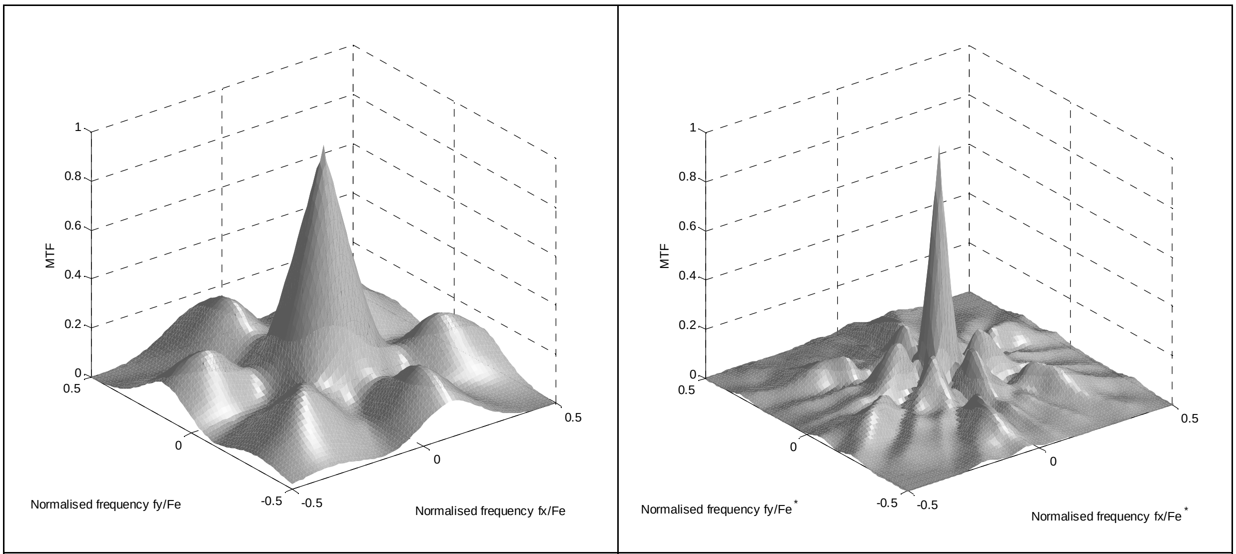
The diameter and the relative positions of the telescopes and the sub-instruments have been optimised such that :

each sub-instrument is able, by interferometric combination of its three pupils, to provide 3 meter resolution images with a 60 km x 60 km field of view, thanks to a 20k x 20k detection matrix. This acquisition mode corresponds to the LRLF mode previously introduced;

the interferometric combination of the 9 pupils as a whole enables the acquisition of 1 meter resolution images with a 20 km x 20 km filed of view. This acquisition mode corresponds to the HR mode.

The figures below represent respectively, the panchromatic MTF of the sub-instruments in the LRLF mode (Fe = 1/3 m^{-1}) and the panchromatic MTF of the HR mode (Fe^{*} = 1 m^{-1}).

It is important to note that the panchromatic MTF of both modes LRLF and HR does not present cancellation till their corresponding Nyquist frequency. Moreover, considering the diameter and the number of telescopes, their relative positions have been optimised in order to maximise the contrast level of each panchromatic MTF.



(a) (b)

Figure 6 – panchromatic MTFs of the LRLF mode (a) et HR mode (b).

4.2 - IMAGE PROCESSING (DECONVOLUTION, ADAPTED DENOISING)

In both modes, despite the configuration optimisation, the collecting area is smaller and the panchromatic MTF is lower than an hypothetical monolithic telescope.

Therefore, to obtain images which quality is comparable to a monolithic system, the interfometric system, in both modes, must :

- have an increased integration time ;
- have recourse to image deblurring and denoising processing (*cf.* figure below).

Briefly, the deblurring processing compensates the raw images for the faintness of their MTF contrast. Such processing has a serious and intrinsic drawback : it makes the detection noise stronger and coloured, thus introducing visual artefacts. Denoising processing, thanks to non-linear processing aims at softening this drawback ([5], [7])

The Figure 7 presents a HR mode raw image, and the result of the deblurring and denoising processing.

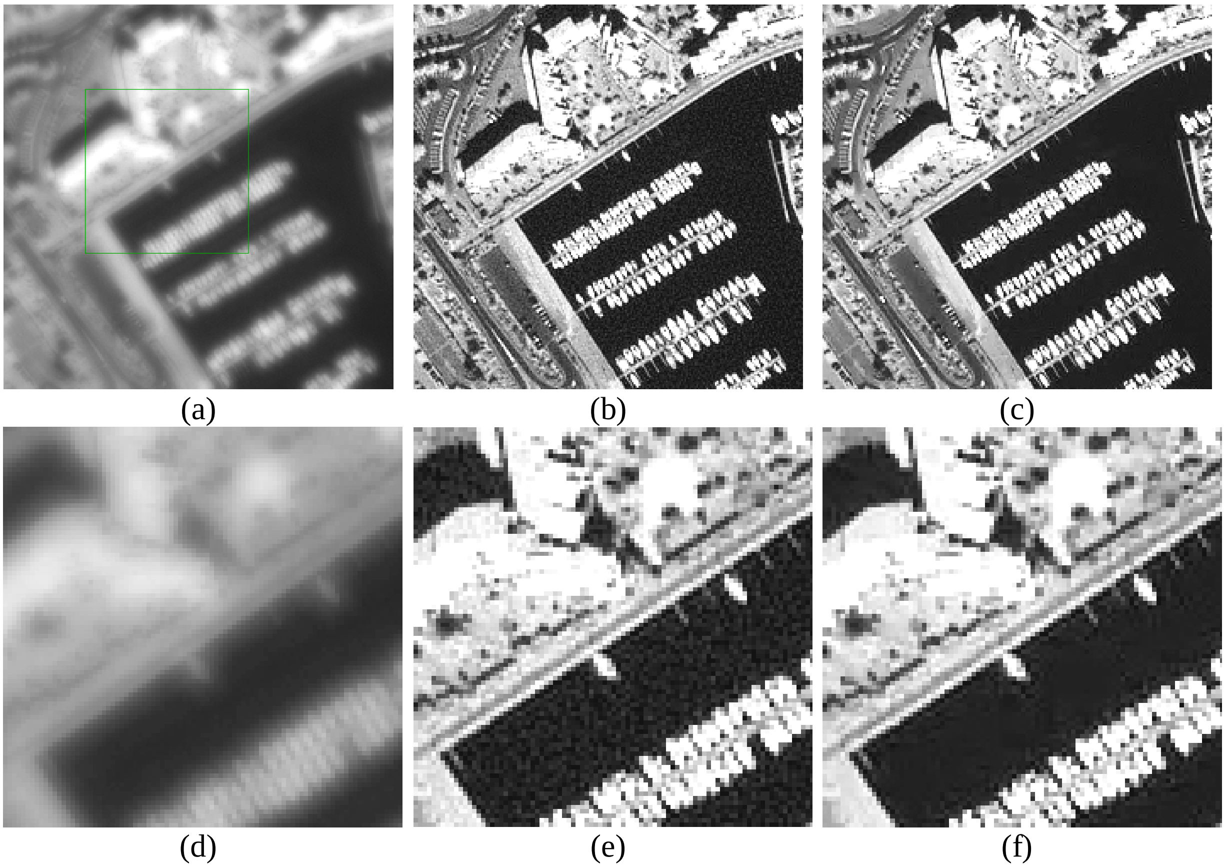


Figure 7 – (a) : simulated HR raw image. (b) deblurred HR image. (c) deblurred and denoised image.(d). Zoom of (a). (e) Zoom of (b). (f) Zoom of (c).

Of course, this image improvement processing is all the more efficient as the signal to noise ratio is high and, therefore, the integration time is long enough.

Nevertheless, from the geostationnary orbit, the line of sight stability allowed by the AOCS sub-system strongly limits the integration time. To circumvent this limitation, the shot over long integration time is “splitted up” into multiple shots over an elementary integration time. The elementary integration time corresponds to the time compliant with the line of sight stability specification. These multiples images are then numerically co-registred, on board or at the ground segment level, and then summed to produce a numerically stabilised raw image with the specified SNR.

The figure below presents, at a small-scale FOV, images provided by the LFLR and HR modes after the image improvement processing.

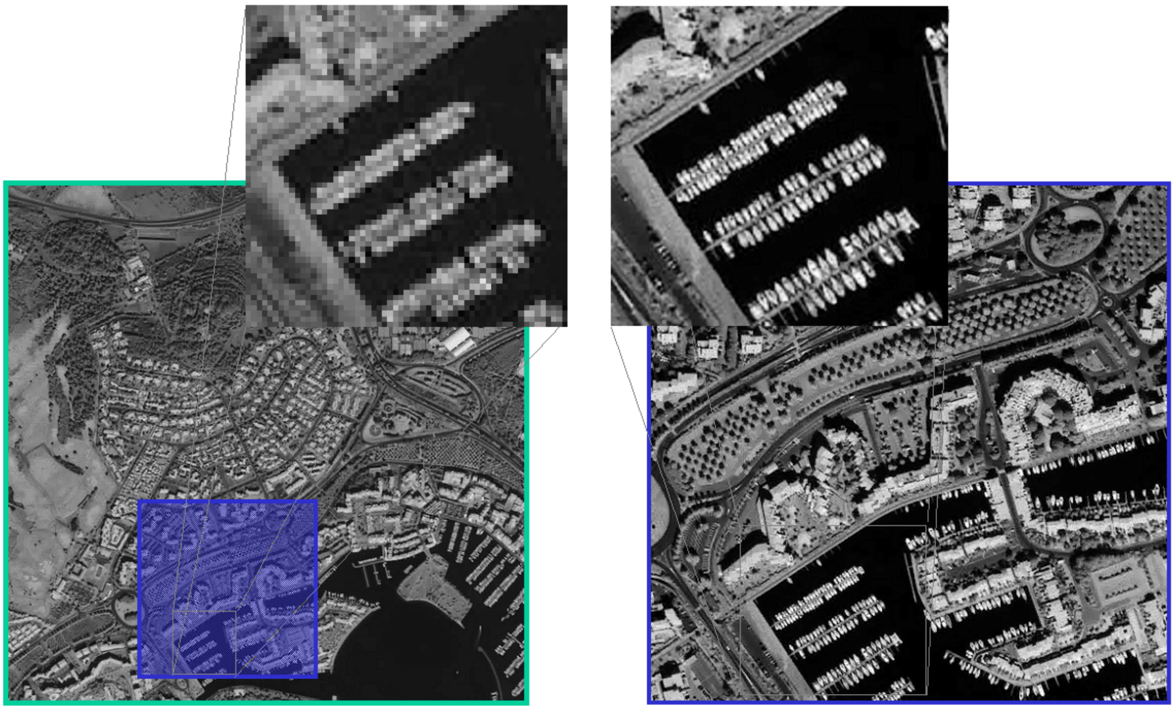


Figure 8 – Resolution and swath comparison between LFLR and HR modes after image improvement processing. (at a small-scale FOV).

5 - CONCLUSION

We have presented in this paper a new instrument concept based on the use of the Optical Aperture Synthesis technique that we believe to be unavoidable in the context of metric resolution observation from the geostationnary orbit.
This multi-instrument concept, du to the interferometric combination of sub-interferometers allows several imaging modes such as a low resolution large field of view mode and a zoom function when using the high resolution mode. In addition, this multi-instrument concept is robust to sub-system failure.
The use of Optical Aperture Synthesis requires deblurring and denoising image processing in order to achieve an acceptable final image quality. This means the adoption of a new approach in the instrument development since such processing has to be considered from the early beginning of the instrument sizing.
Optical Aperture Synthesis and multi-instrument concepts are studied in the Alcatel Space Research Department.

6 - BIBLIOGRAPHIE

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